Missing Baryons and the WHIM

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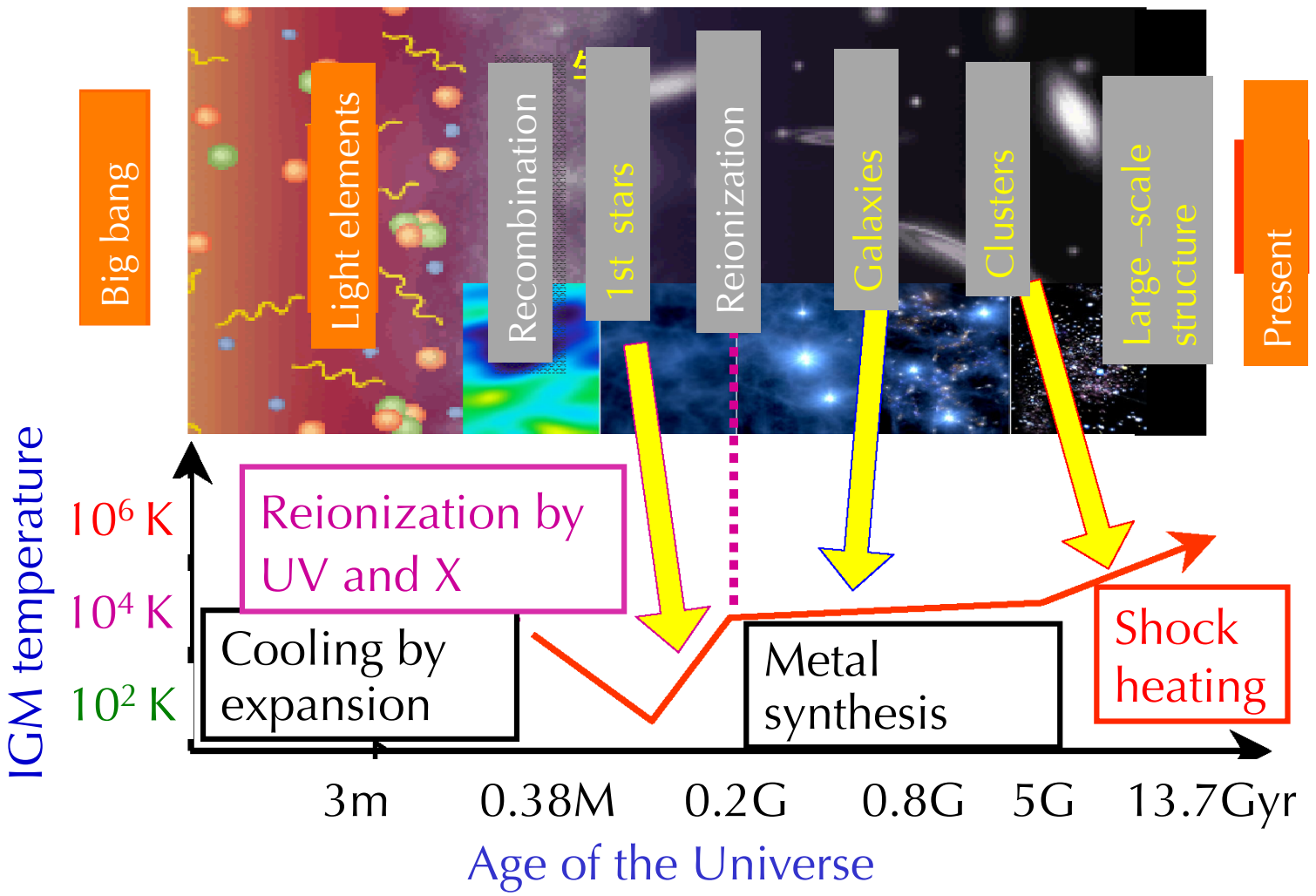
- Science of missing baryons and observational status in X-rays
- OVI absorption results in UV
- Absorption study with IXO XGS
- Emission study with IXO XMS
- Resonance scattering
- Summary

Thermal history of the universe

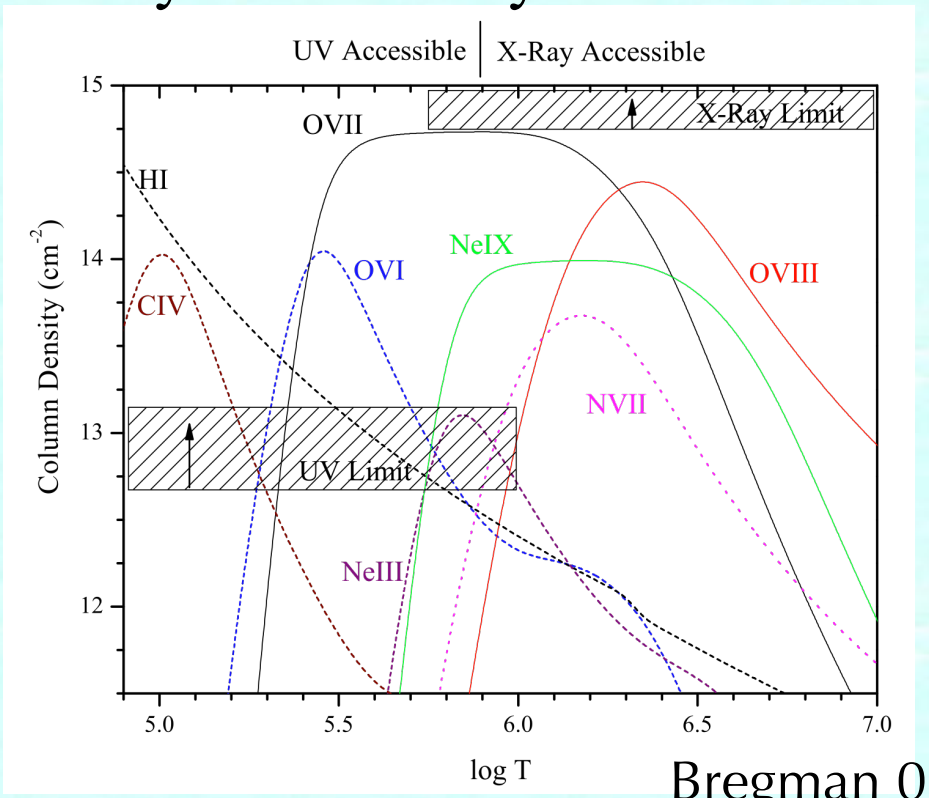


WHIM (warm-hot intergalactic medium) will tell us the evolution of the hot-phase material in the universe

Baryon phase

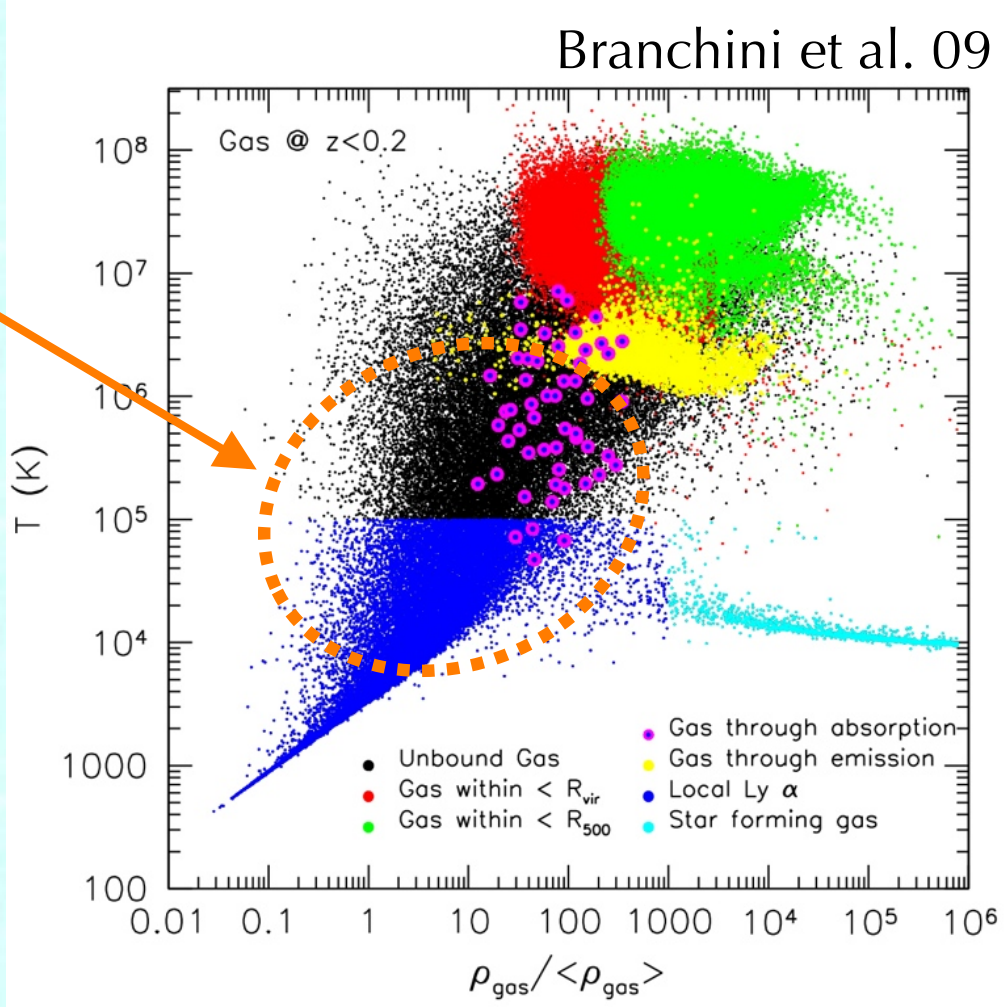
Wide area in the baryon phase space is unexplored

Oxygen line probes the dark baryon efficiently



Bregman 07

Branchini et al. 09



EDGE consortium

Cosmic structure

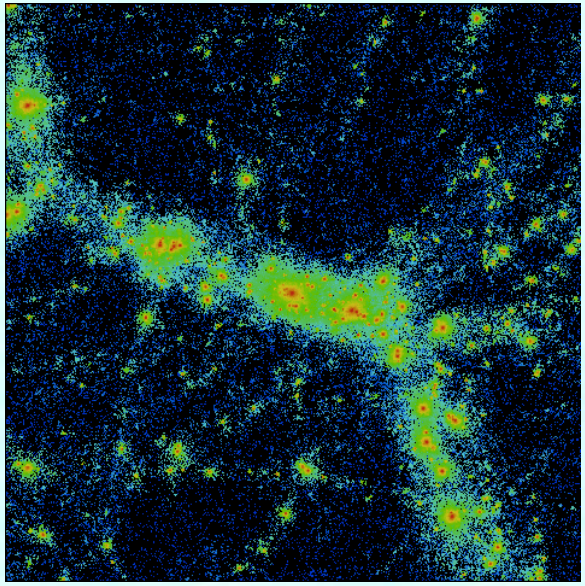
WHIM (10^5-10^7 K) traces the cosmic large-scale structure
= "Missing baryon"

Typical matter density:
$\delta\,(=n/\langle n_B\rangle)$ = 10 - 100

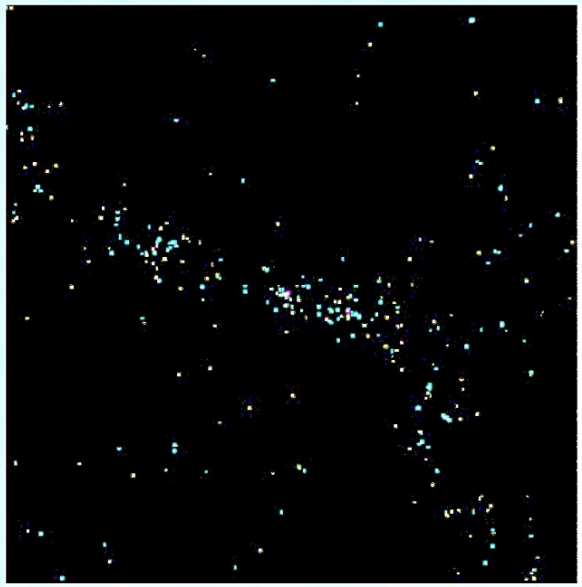
Yoshikawa et al. 2001, ApJ, 558, 520

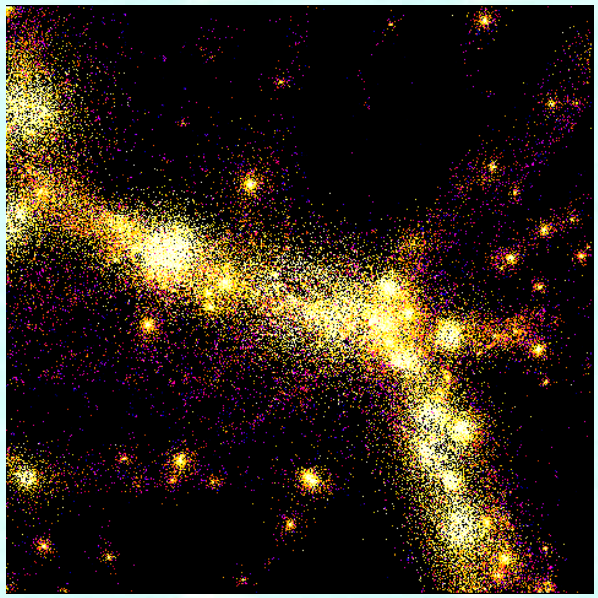
size = 30 h^{-1} Mpc
≈ 5 deg at z=0.1

Dark matter

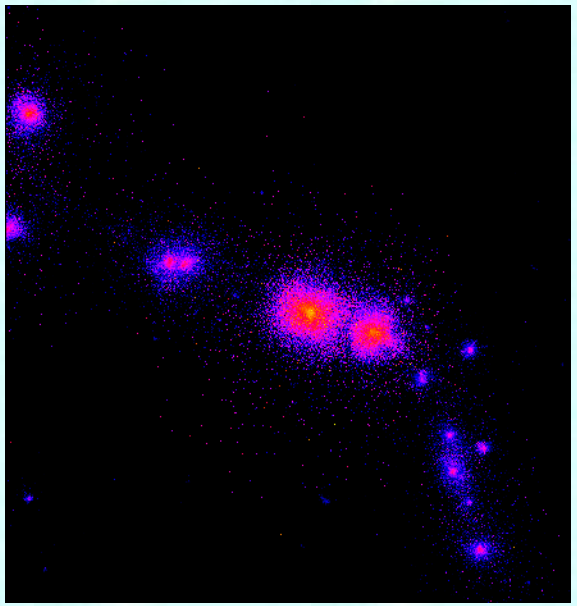


Galaxies (~10^4K)





IGM (10^5-10^7K)

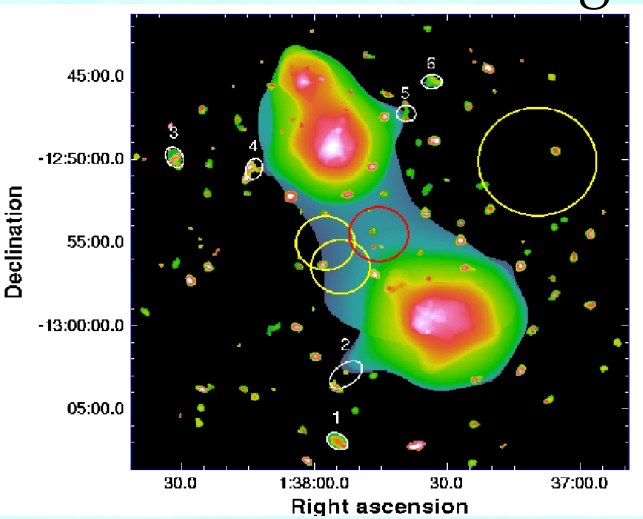


Cluster gas (10^7K)

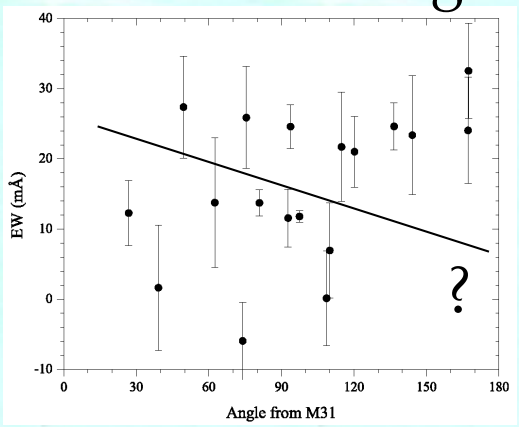
XMM study of WHIM

- Werner et al. 2008: X-ray bridge between A222 and A223 ($z = 0.21$)
  - kT ~ 0.9 keV, $\delta \sim 150$, continuum only
- Bregman & Lloyd-Davis 2008: Local OVII absorption is due to Galactic halo (not by Local group medium)

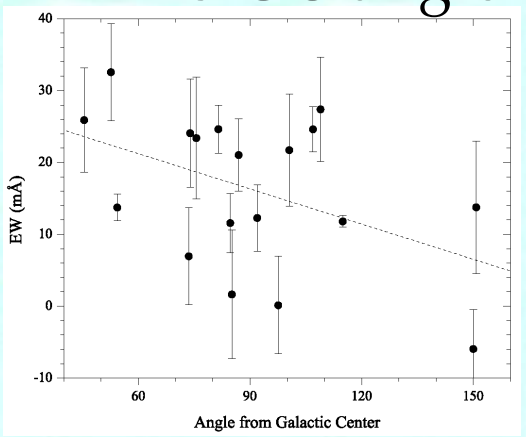
A222-A223 bridge



EW vs M31 angle



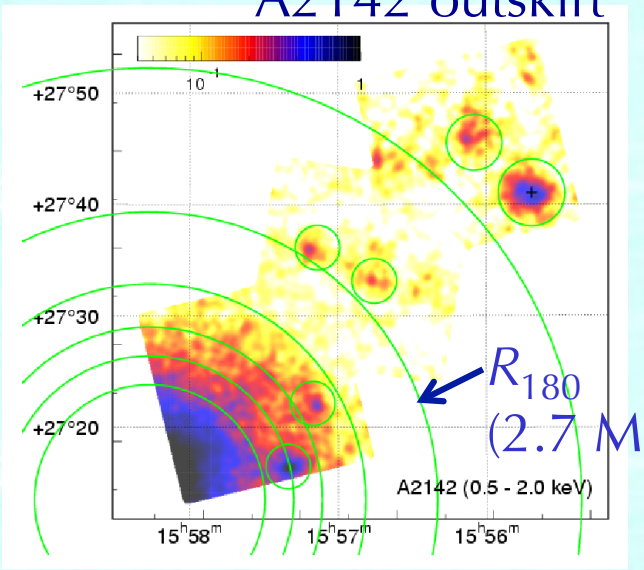
EW vs GC angle



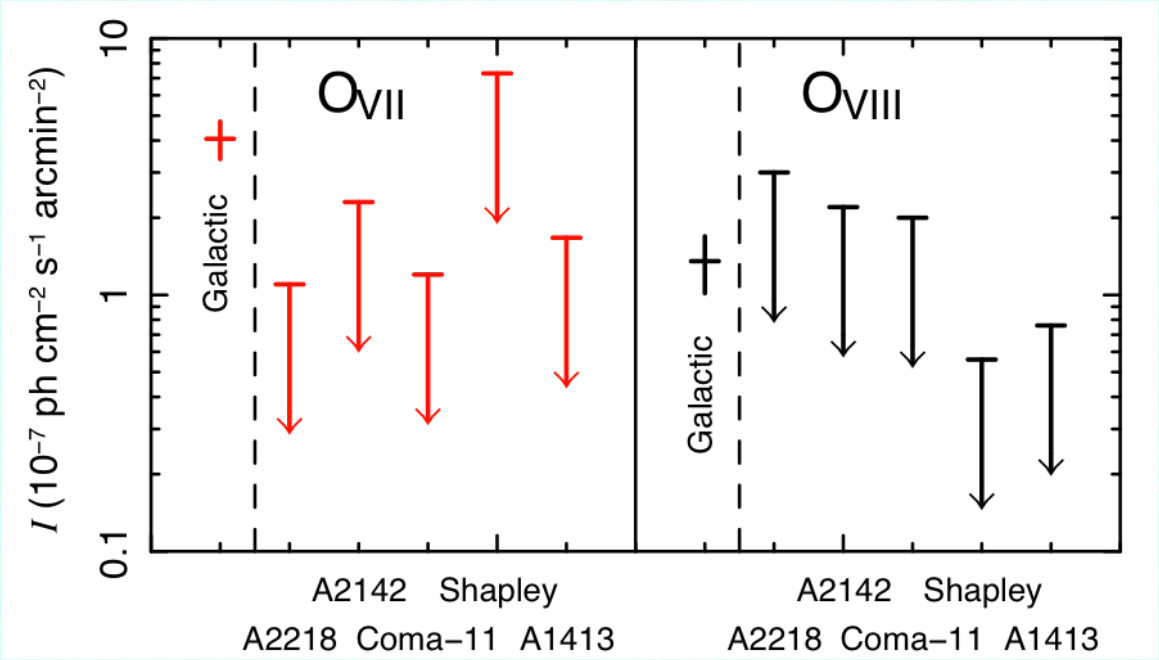
Suzaku search for WHIM

- Suzaku is searching for WHIM in cluster outskirts and in superclusters, with no positive detection of redshifted O lines yet
- Suzaku is giving fairly low upper limits ($\delta < 300$ assuming line-of-sight depth of 2 Mpc and $Z_O = 0.1$ solar)
- Suzaku will continue searching for WHIM in all possible locations

A2142 outskirt



Akamatsu + in prep



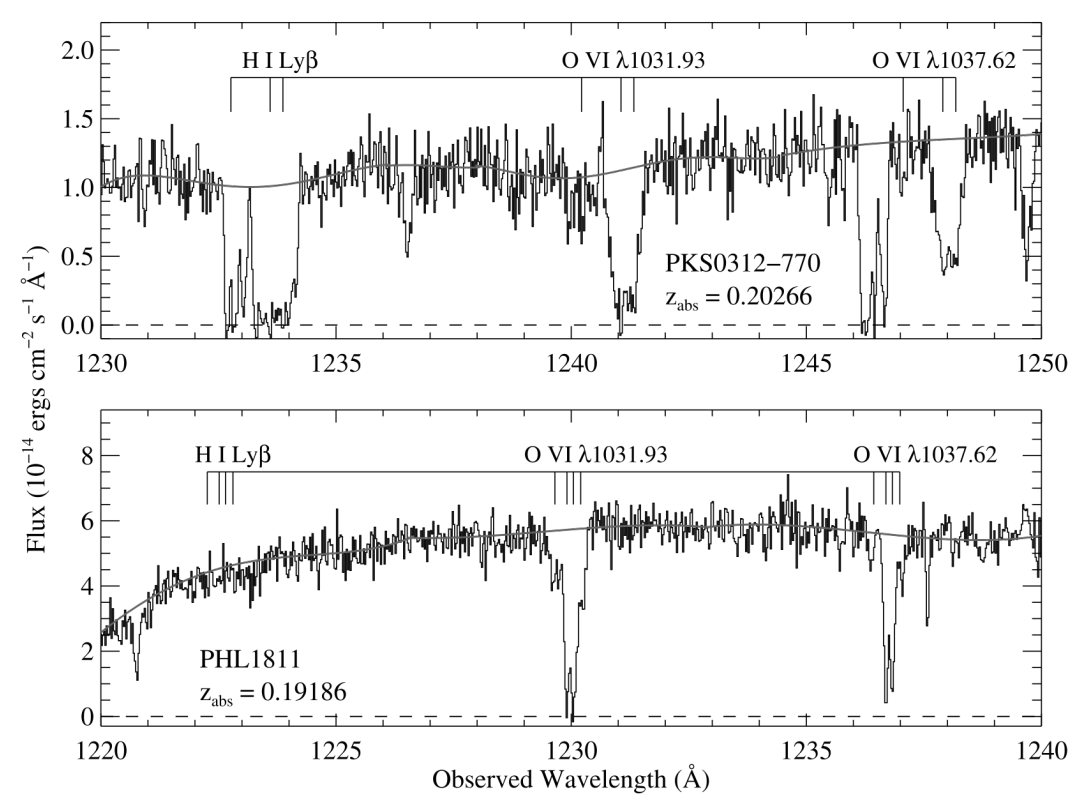
OVI absorption lines

- 30 – 50 absorption systems have been detected against 16 quasars using STIS
- $\Omega(\mathrm{OVI}) \sim 2.4 \times 10^{-7}$ ($\rightarrow \Omega_b \sim 0.002$; 0.1 solar, ionization frac. = 0.2)
- Are they WHIM?
  - > 95% of OVI systems are associated with HI (Thom and Chen 08)
  - Broad lines may not be due to thermal, possibly by turbulence witt $v \sim 30$ km/s
  - No sign of OVII absorption features corresponding to known OVI absorbing clouds (Yao et al. 09)
- Photoionization of cool HI clouds may largely contribute to OVI absorption (not the WHIM)

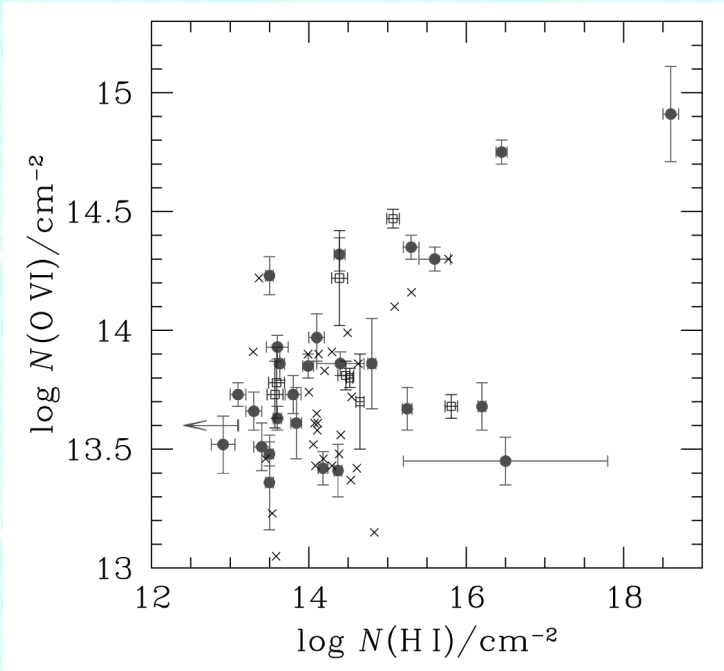
Definite confirmation of WHIM necessary

OVI measurements

Strong OVI doublet (1031/1037) absorption (Tripp et al 08) with STIS



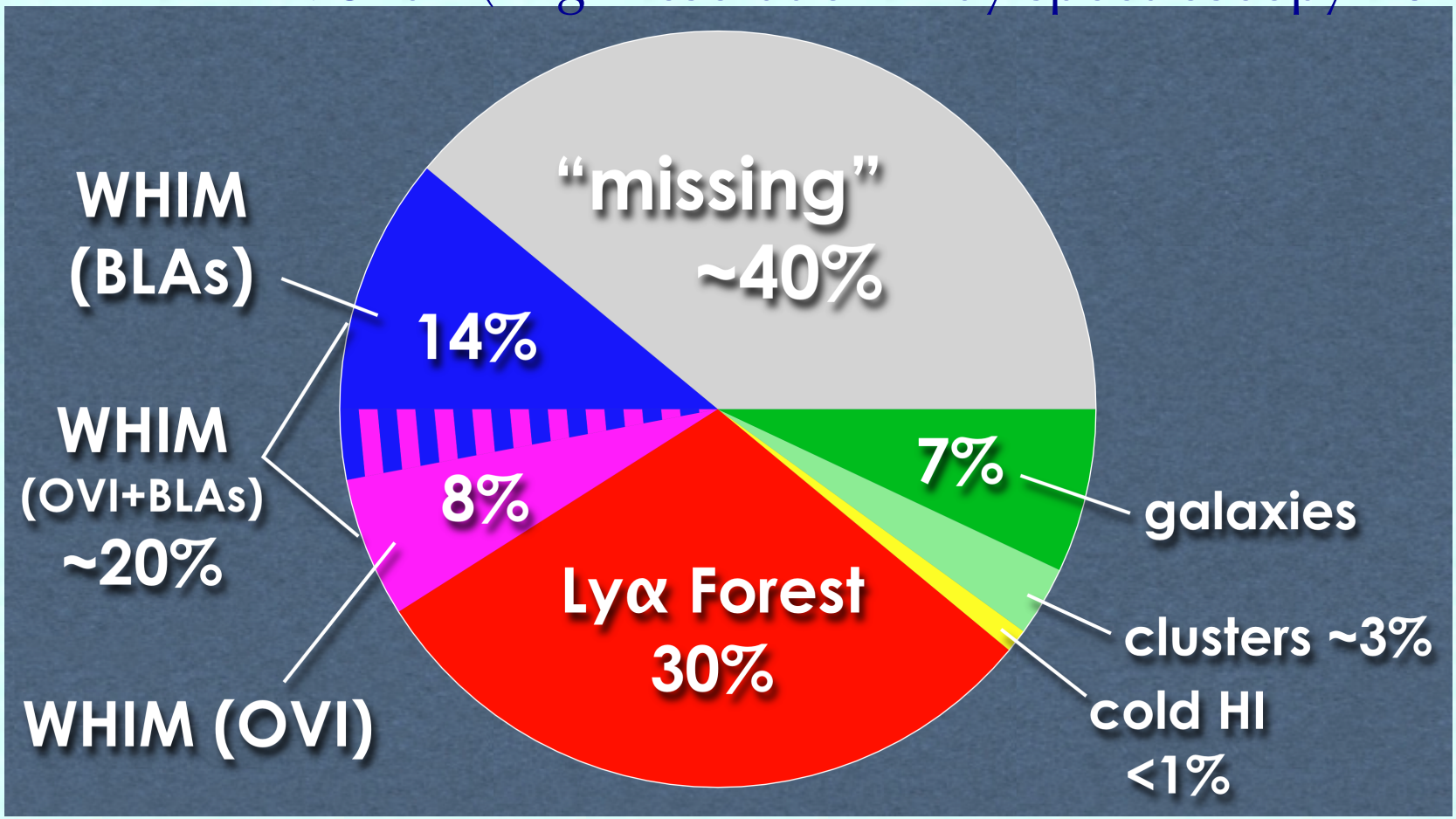
Association of OVI and HI clouds (Thom and Chen 08)



COS will give substantial improvement

Baryon census

M. Shull (High resolutionX-ray spectroscopy 2010)



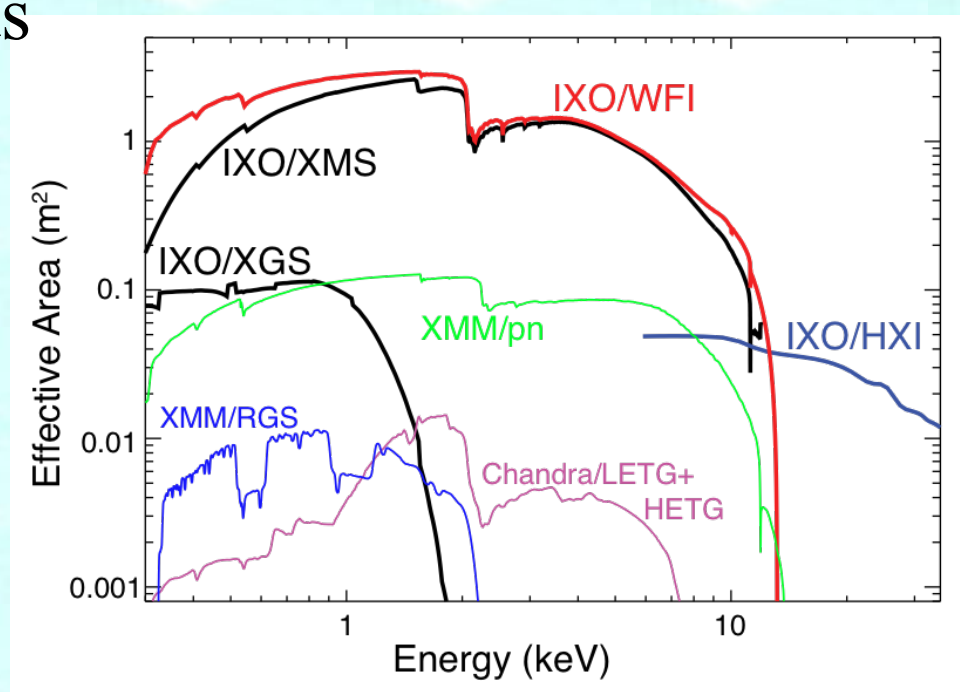
Based on OVI measurements

Some part of OVI may be from Lya forest (photoionized)

COS observations will clarify origins of OVI line

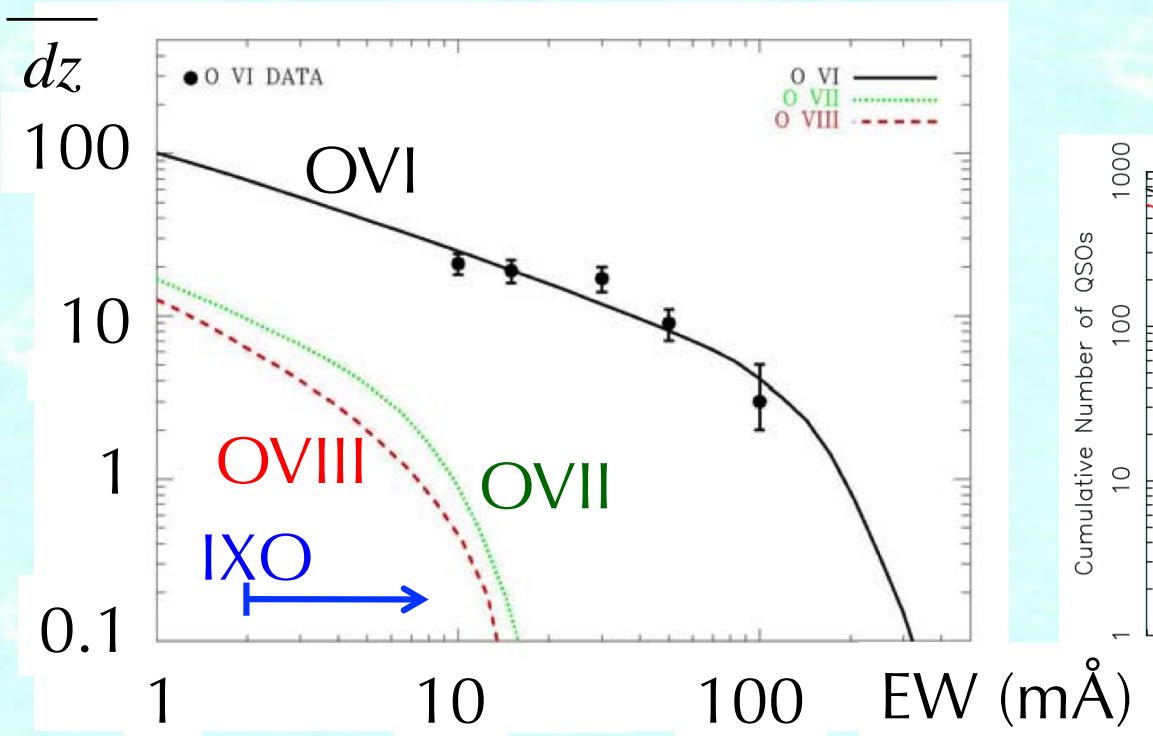
IXO: grating spectrometer

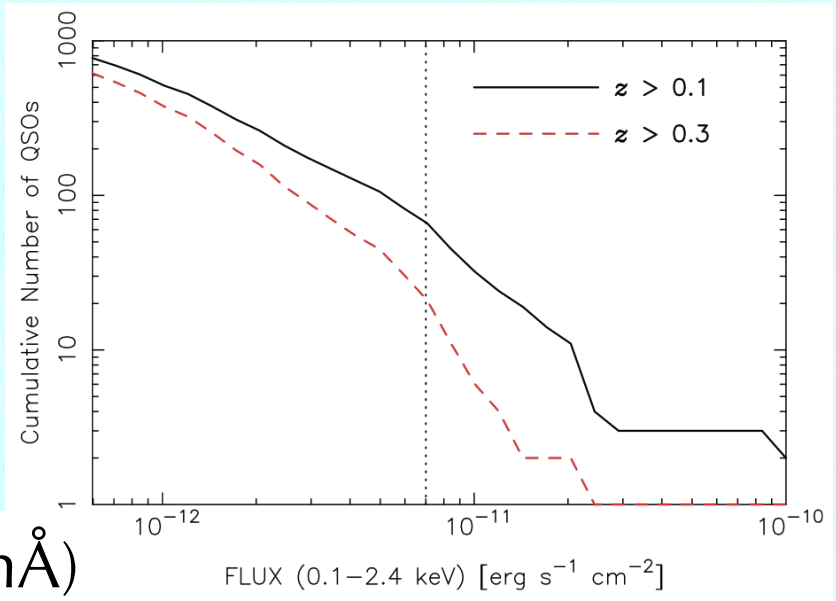
- Big jump from Chandra and XMM-Newton grating spectrometers by factor of 10 in effective area and 15 times higher sensitivity
- Sensitive to Equivalent Width ≈ 2 meV
- $R = 3000$ can resolve $v = 100$ km/s, such as structures of galactic winds



IXO: absorption study

- Detection of OVII, OVIII absorptions: WHIM presence beyond any doubt
- There are > 100 useful AGNs for absorption study
- Predicted *dN*/*dz* of OVII, OVIII clouds (normalized with OVI results) shows several absorption systems per AGN will be detected

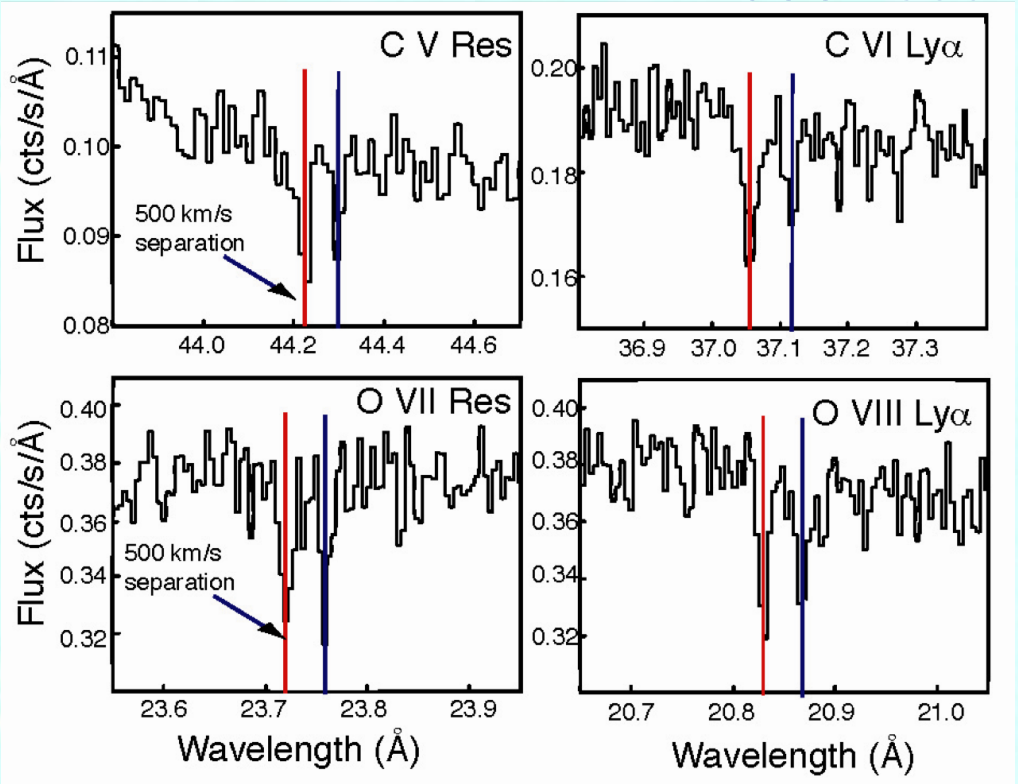




Expected absorption features

- AGN with $F_X = 5 \times 10^{-11}$ erg cm^{-2} s^{-1} (0.5 – 2 keV) will give enough signal for IXO
- A total of 18 Msec observations for ~ 30 AGN
  → 100 absorption clouds

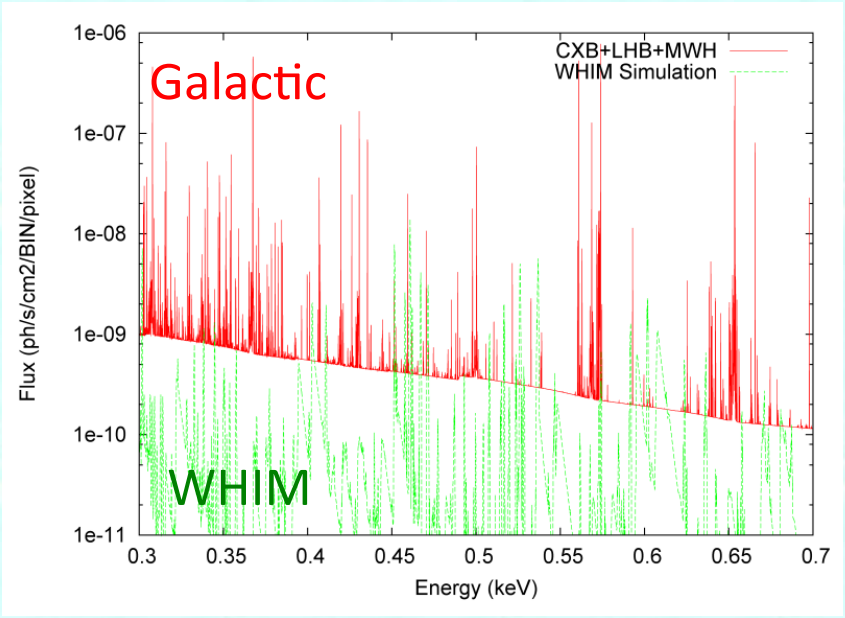
600 ksec

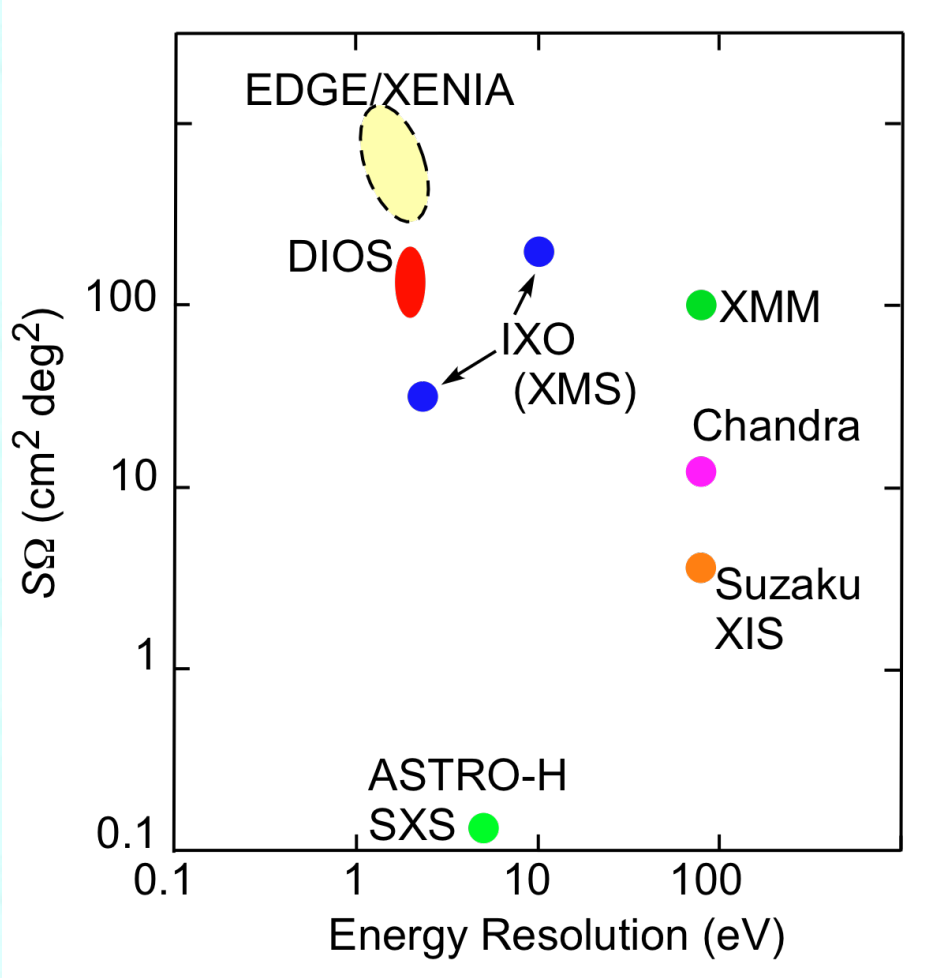


Bregman et al. IXO-WP

WHIM emission study

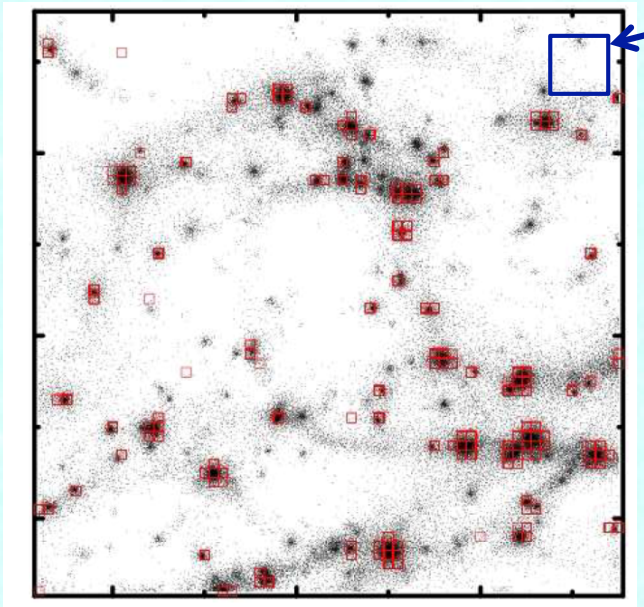
- Grasp of XMS: equally large as those of dedicated missions
- 5” angular resolution resolves 16 kpc at $z = 0.2$ (galactic outflows)





WHIM in emission with IXO

- Wide-area mapping with 20-30 ksec per position over 1 Msec can cover 30 ×30 arcmin^2 (6 Mpc at $z = 0.2$)
- Deep pointing on galaxies will show galactic outflows – metal enrichment process of intergalactic space



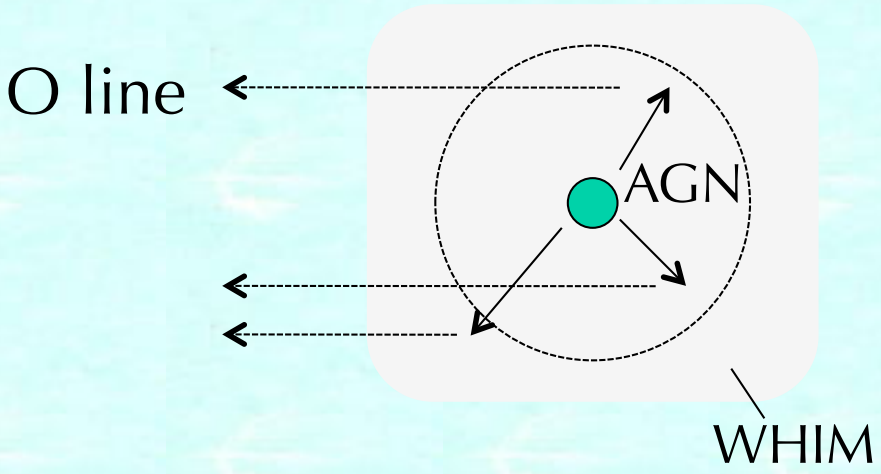
5 deg x 5 deg at $z = 0.2$
(60 Mpc)

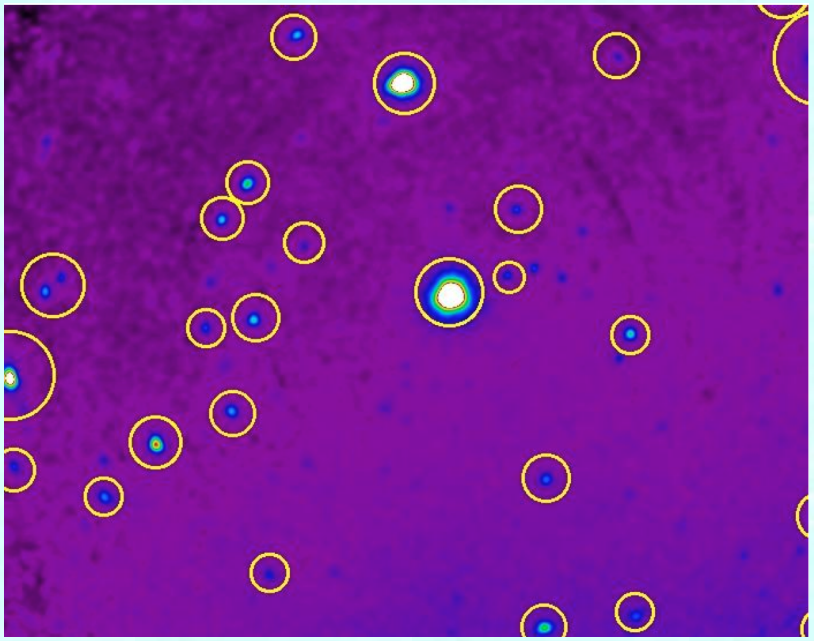
WHIM search using resonance scatting

- Churazov et al. 01, MN 323, 93
- WHIM can be surrounding bright AGNs
- Part of continuum X-rays undergoes resonant scattering by WHIM gas
- A few Mpc region around bright AGNs will shine in OVII and/or OVIII lines
- Rough estimation shows that an AGN with $L_X = 10^{46}$ erg/s at $z = 0.2$ can produce about 100 OVII counts with IXO over ~ 5 arcmin region in 100 ksec observation

WHIM with resonance scattering

- Part of AGN X-rays will be resonantly scattered by OVII and OVIII ions in surrounding WHIM
- This will produce oxygen-line halos around AGNs





Churazov: High-res X-ray spectroscopy 2010

Summary

- Absorption and emission studies of IXO will reveal all phases of warm-hot baryons within $z \leq 0.5$
- WHIM will give us unique information about thermal and chemical evolution of the universe
- Absorption study with IXO will probe low-density WHIM clouds ($\delta < 100$)
- Emission measurement will also show us the spatial structure (filaments, outflows) of WHIM
- Resonance scattering may show oxygen-line halos with ~ Mpc scale around bright AGNs